CNM Users Meeting 2009

CNM Users Meeting Focus Session on "Materials and Fabrication for Nano Electro Mechanical Systems (NEMS)" October 6, 2009

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Many Nano-Electro-Mechanical System (NEMS) devices are currently being developed for unique applications in sensing, telecommunications, signal processing, data storage, and more. As characteristic device dimensions shrink to the nanoscale, novel fundamental and technological challenges need to be addressed before the full potential of these devices can be demonstrated. Examples of these challenges are: development of extremely precise mechanisms of nanofabrication, advancements in nano-metrology, and sensing and manipulation of short-range quantum forces. This full-day focus session provided an opportunity to identify the most challenging aspect of fabrication of NEMS devices and to evaluate putative solutions to them. The focus session consisted of a number of short presentations by leading experts in the area of nano-mechanical systems and general discussions with all the participants.

A variety of NEMS-enabled novel applications were discussed in detail by several speakers.

Prof. Vinayak Dravid (Northwestern University) described his work with nano/micro-cantilevers for sensing and imaging. His group utilizes MOSFET-embedded cantilevers for measuring the signal transduction of molecular binding induced surface stress into nanomechanical motion of microcantilevers, thereby providing a new label- and optics-free all-electronic detection and sensing approach. Additionally, using cantilevers as source and detector for ultrasound holography, they have developed a new sub-surface nanoscale non-destructive imaging technique for nanoscale metrology for engineering structures and biological applications. His presentation covered the core philosophy of integrating advances in microelectronics and nanofabrication with biology for development of sensing, diagnostics and imaging systems.

Dr. J. Provine (Stanford University) presented his work on nano-fabricated freestanding 2-D photonic crystals (PC) that can be used as broadband mirrors with high reflectivity. By controlling the structure and geometrical dimensions, PC slabs can support guided resonances that couple to external radiation in ways that profoundly change the optical properties. This can be utilized to design compact optical devices such as mirrors, filters, lasers, and sensors. The main advantage of 2-D PC slabs is that they can be designed to achieve comparable performance of 1-D PCs, or Bragg-stacks, but in a more compact form. Additionally, he discussed a few applications of 2-D photonic crystal slab integrated optical microsystems such as photonic crystal mirror MEMS scanners for high-power beam steering, and photonic crystal fiber tip sensors for remote sensing in harsh environments.

Dr. John Moreland (NIST) provided an informative summary of state-of-the-art magnetic MEMS and presented an innovative "nano-magnetic manipulator" consisting of a micro-fluidic device integrated onto MRAM structures. This unique structure would create novel mechanisms to control NEMS devices inside fluids and would advance the fields of molecular electronics, single molecule DNA chip and single molecule manipulation.

The dynamics of NEMS devices in fluidics was discussed in detail by Prof. Kamil Ekinci (Boston University). Because many novel applications of these devices are in fluidics, he considered the operation of NEMS resonators immersed in liquids. In this situation, a NEMS resonator loses most of its vibrational energy to the fluid and, as a consequence, the quality factor (Q) of the resonator decreases significantly. Reductions in Q factor result in a reduction in the NEMS sensitivity limiting seriously their use for sensing.

In order to solve this serious problem, he is studying NEMS resonators with textured surfaces with reduced dissipation in water.

Nanomechanical single electron shuttles are an example of another novel use of NEMS devices. Chulki Kim (University of Wisconsin) presented experimental results of self excitations in nanomechanical single electron transistors. The novelty of this structure allowed him to observe Coulomb blockade in suspended nanometer-size metallic islands.

Several experts described the challenges associated with using novel materials for NEMS fabrication.

Prof. Mehran Mehregany (Case Western Reserve University, OH) presented his group's work on poly-SiC based NEMS. He showed his novel approach toward high-temperature computing with all-mechanical logic based on SiC NEMS switches. SiC is an attractive material platform for high temperature applications due its excellent mechanical properties, broad media compatibility and compatibility with nanoscale fabrication processes. Currently, his efforts are focused on understanding the reliability and failure mechanisms in these devices.

Dr. Rachel Cannara (NIST) is exploring the origins of nanoscale friction for technologically relevant materials. Her work considers the use of diamond as an alternative to silicon for applications where adhesion and wear are unavoidable.

Dr. Ani Sumant (CNM) reported on opportunities and challenges for ultrananocrystalline diamond (UNCD) as a structural material for NEMS. He presented the science performed to understand key aspects of UNCD film synthesis and the first UNCD based MEMS switch monolithically integrated with CMOS controlling electronics.

A comprehensive description of the use of diamond-coated nanoprobes for tip-based nanofabrication was given by Dr. Patrick Fletcher (University of Illinois at Urbana-Champaign, IL). His approach to nanofabrication uses atomic force microscope tips capable of self-heating to temperatures larger than 800^{o}C and scanning over large distances at high speed. Tip wear represents the biggest challenge for this application. UNCD coated tips were studied and they demonstrated exceptional wear resistance and dimensional stability under the harsh operation conditions typical of this technique. Overall, the diamond-coated probes were much less prone to fouling than silicon probes and no signs of delamination were observed.

These talks described current challenges in the use and design of NEMS devices and presented innovative solutions to overcome current limitations of this promising technology. This focus session generated considerable interest among the participants resulting in novel collaborations between research groups.